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Seismic Fragility Analysis of RC Frame Structure

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ABSTRACT: In recent years, number of studies have been carried out for the evaluation of vulnerability of structure during seismic events. Fragility analysis is one of the important probabilistic approach to estimate the damage data at different damage state during seismic events. The G+14 Reinforced Concrete frame structure is considered for analysis. The structure is analysed in ETABS by Non-linear Pushover Analysis and Incremental Dynamic Analysis. Fragility curve developed for Non-linear Pushover Analysis from results obtained by capacity spectrum method for different damage states. Fragility curve developed for Incremental Dynamic Analysis for different damage states by considering set of 3 real ground motions. The fragility curves are derived from analytical method. The fragility points for different damage states are derived from analytical formula. Fragility curve is plotted for probability in Y-axis and spectral displacement in X-axis for 4 different damage states from Non-linear Pushover Analysis. From Incremental Dynamic Analysis fragility curve plotted for probability in Y-axis and peak ground acceleration in X-axis for five different damage state. The behaviour of fragility curve after achieving the 100% probability for different damage state is constant.

KEYWORDS: Fragility analysis, non-linear pushover analysis, incremental dynamic analysis, fragility curve, damage.

I. INTRODUCTION

Earthquakes are distinct from other disasters because they bring destruction through the collapse of man-made structures rather than direct loss of life. Buildings are the major structures that are exposed to damage when earthquakes are triggered. Earthquakes cause economic losses apart from the torturous pain of loss of lives. In past earthquake events, such as the Latur earthquake 1993, Bhuj earthquake of 2001, the Nepal-India earthquake in 2015, and the Kashmir earthquake in 2005, buildings and infrastructures were severely damaged and collapsed. During these events, the worst damages were often recorded in cities. For example, many people were killed and many people get injured by falling building debris. Therefore, building damage is the main source of seismic losses during earthquakes. To overcome or solve this problem, fragility curves were introduced by researchers to serve as one of main tool in assessing damage and loss during earthquakes. Seismic risk assessment is the first step within the disaster prevention strategy and in reducing the associated risks of infrastructures. The comprehensive studies of seismic risk are often divided into 3 components- Hazard, Vulnerability and Exposure. Hazard is that the event capable of inflicting harm whereas Vulnerability represents the degree of loss of a component ensuing from a hazard. Exposure is that the number of parts like population, the economic activities, and therefore the constructions and structures exposed to a hazard. It's well understood that it's not the earthquake that kills however the failure of the buildings exposed to those earthquakes. So, understanding the behavior of the buildings throughout earthquake may be a growing space of research. Assessing the vulnerability of the structures as seismic performance are often useful for risk mitigation and emergency response coming up with. In general, the curves are generated from real earthquake damage data to estimate or predict whether the damage meets or exceeds a certain performance level for a given set of ground motion parameters. In addition, the curves can be applied to predict both pre- and post-earthquake situations. These curves are unique because every building has specific fragility analysis. There are studies have reported different methodologies used to develop fragility curves.

Many previous studies, present a brief historical background of fragility curve. Fragility curves are defined as the probability of reaching or exceeding a specific damage state under earthquake excitation.

The general equation to develop fragility or conditional probability is expressed

$$\text{Fragility} = P[\text{LS} | \text{IM} = y] \quad \text{Equation (1.1)}$$

where,

LS is the limit state or damage state (DS),

IM is the intensity measure (ground motion), and

Y is the realized condition of ground motion IM.

Various equations were derived from this research. However, all the equations are based on above equation, which is a

general equation for generating a fragility curve. Although most of these studies used different equations to generate their versions of the seismic fragility curves. Structural Types Fragility curves were discussed based on three types of structures, namely, steel, reinforced concrete, and timber. The fragility curves for buildings are categorized into three types. These types are low-, mid-, and high-rise buildings based on the number of story's. The important factors of vulnerability, which are also available for large databases, include a number of storeys, age of construction, regularity in plan and elevation, infill regularity, and building position in the block. Thus, classifying buildings is one of the significant factors that must be considered in developing fragility curve. Differences in materials, height, and number of bays also result in different shapes of vulnerability curves.

II. LITERATURE SURVEY

Variability functions and fragility curves observed by considering the ground motion and records and structural modelling uncertainties for low-, mid- and high-rise RC buildings in Patna, India, which is a region of high seismicity by **Kumar and Samanta [1]**. For modelling uncertainties, they considered the material, geometrical, and design as random parameters. In this study, they selected the random parameters were purely based on the investigation of buildings in the Patna region. The buildings were modelled and analysed using nonlinear static (NLS) pushover analysis. The monotonic load in a triangular pattern was applied for NLS analysis to get pushover curves. The pushover curves were subsequently converted into capacity curves considering the dynamic characteristic of the first mode of vibration. The obtained capacity curves were utilized to derive the variability in the capacity spectrum for different categories of RC buildings. By calculating for both the uncertainties, lognormal variability functions were determined, and seismic fragility assessment was performed for different building categories in Patna, India.

Fragility curves established by **Murat and Polat [2]** for mid-rise RC frame buildings located in Istanbul and investigated the effect due to the number of stories of the building on fragility constraints. To study these effect buildings with 3, 5 and 7 story were designed according to the Turkish seismic design code. IDA using twelve artificial ground motions were applied to these sample building and fragility curves were developed considering a lognormal distribution for the IDA result. Also, the regression analysis was carried out between fragility parameters and the number of stories of the building. It was found that fragility parameters change widely due to the number of stories of the building. Finally, the maximum allowable inter-story drift ratio and spectral displacement values that satisfy the immediate occupancy and collapse prevention performance level requirements were estimated using obtained fragility curves and statistical method.

The variability in seismic fragility functions for frames of different heights for the most vulnerable condition of structure using nonlinear time history analysis studied by **Apu and Sinha [3]**. They analyzed the total of 4, 8 and 20 stories RC moment resisting two-dimensional frames. The ground motions (GM) were selected as per the conditional mean spectrum and these were conditioned on a target spectral acceleration at the concern time period. RC frames were designed and detailed as per Indian standards. A concentrated plasticity approach was adopted for non-linear analytical modeling of the RC frames. Fragility functions derived following a lognormal distribution from incremental dynamic analysis curves and maximum estimation of the response is obtained for fitting curves with observed fragility. The fragility functions of the three structures showed that under critical or extreme conditions of GM the taller buildings had higher fragility than the shorter buildings for each level of limit states even though both were designed to meet their code-level design forces.

The advancement in computational methodologies and large database of existing buildings, fragility analysis can be implemented for precise vulnerability assessment of buildings was studied by **Tarannum Yasmin et al. [4]**. The vulnerability curves can be categorized into three groups-empirical, analytical and hybrid. Empirical approach includes Damage Probability Matrices and Vulnerability Functions, which depend on the damage motion relationship statistics observed after an earthquake. Analytical curves adopted damage distributions simulated from the analyzed structural models. Hybrid curves overcome the deficiencies of the above two approaches by combining post-earthquake damage statistics with simulation techniques. They reviewed the importance of fragility analysis using existing methodologies. The methodologies focused on their key features highlighting limitations and suggests the way forward for selection of appropriate assessment method for seismic vulnerability assessment of existing buildings and the incorporation of experimental vibration-based methods.

The points related with seismic vulnerability, damage and risk evaluation were studied with review of widely used possibilities with seismic evaluation of structures by **Alex H Barbat et al. [5]**. The capacity spectrum method and developing the fragility curve for seismic damage scenarios were discussed. From the capacity spectrum method, the seismic risk of the buildings of Barcelona, Spain, was analysed. The information on the buildings was obtained by collecting, arranging, improving and completing a broad database of the dwellings and current buildings. They used the

Arc View software to create a GIS tool for managing the collected information in order to develop seismic risk scenarios. They investigated the vulnerability of the buildings was significant in Barcelona and the expected seismic risk was considerable in spite of low to moderate seismic hazard.

III. METHODOLOGY

The following method is adopted for the analysis of RC frame building,

- A literature review is carried out, based on the objectives of the study.
- ETABS 2019 software is used for modelling of the RC frame structure.
- Analyse the model using pushover analysis and incremental dynamic analysis as per IS 1893-2016.
- The ground motions taken for dynamic analysis is Bhuj, India-Burma border and Uttarkashi earthquake.
- Material used is M25 and Fe-500
- The column size is Column 1 is 750mm x 500 mm and Column 2 is 450mm x 300mm
- Beam size is 300mm x 450mm and slab thickness is 150mm.
- Finally, the conclusions are drawn based on the obtained results.

IV. MODELLING

This chapter involves in modelling of RC frame system of G+14 with a storey height of 5m for first 4 storey and above that 3m height. The grade of concrete used M25 and rebar used Fe 500.

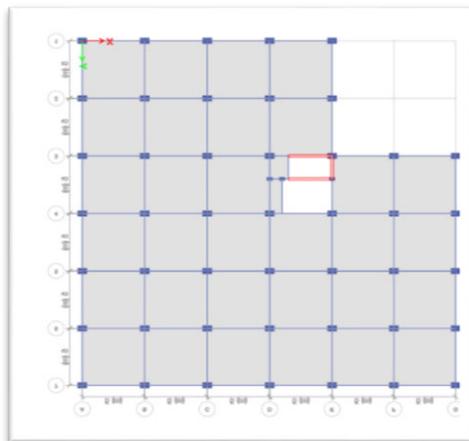


Figure 1 Plan of Structure up to 4th Storey

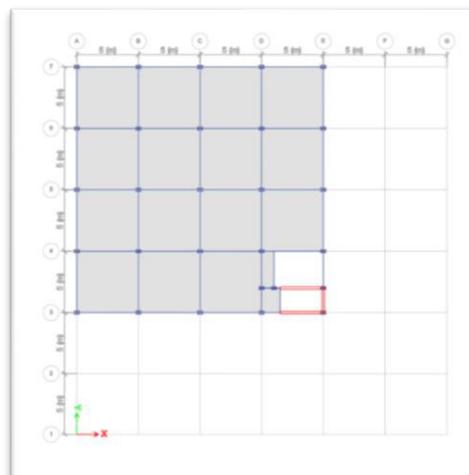


Figure 2 Plan of Structure above 4th Storey

Figure 1 & 2 shows the plan of the structure upto 4th storey and above 4th storey modelled in ETABS.

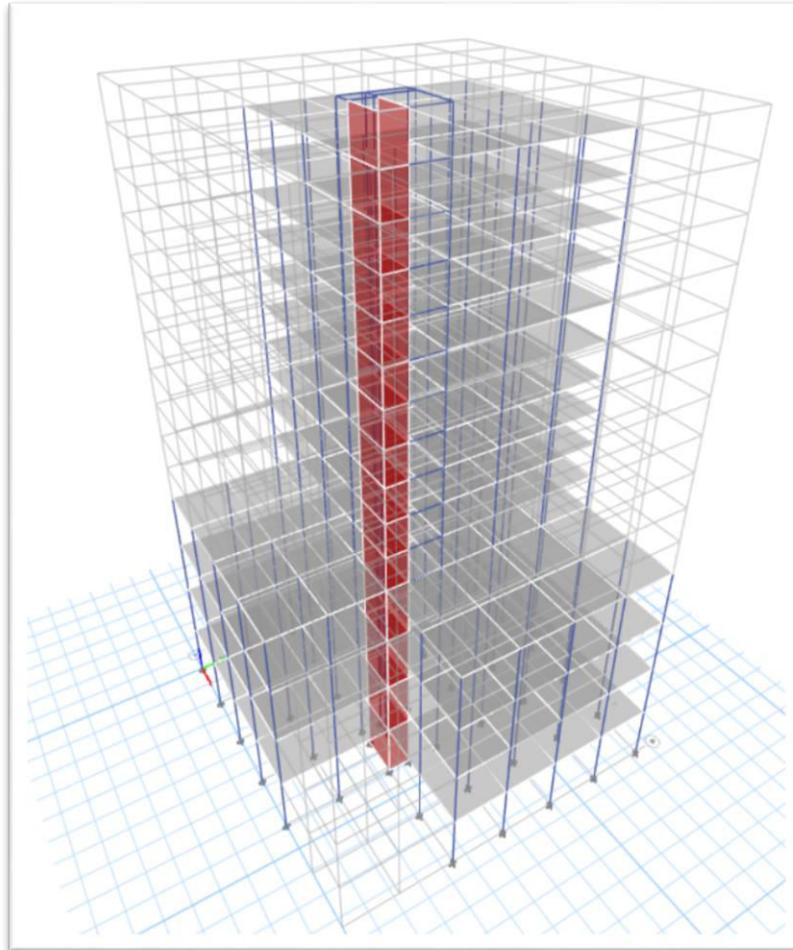


Figure 3 Model of G+14

Figure 3 shows the isometric view of the RC frame structure modelled in ETABS.

V. RESULTS AND DISCUSSIONS

1) Development of Fragility Curve from Pushover Analysis by Capacity Spectrum Method

Fragility curves can be obtained in a simplified way starting from the bilinear representation of the capacity curves. Table 1 shows how the thresholds S_d are obtained in this case in function of the yielding displacement D_y and the ultimate displacement D_u of the structure.

Table 1 Damage State Threshold

Sr. No	Spectral Displacement	Median Spectral Displacement S_d	Damage State Threshold
1	$0.7 D_y = 0.49$	S_{d1}	Slight
2	$D_y = 0.7$	S_{d2}	Moderate
3	$D_y + 0.25(D_u - D_y) = 1.25$	S_{d3}	Severe
4	$D_u = 2.9$	S_{d4}	Complete



The Non-linear pushover analysis is done and from the results the fragility curve developed for different damage states. From the pushover analysis the target displacement is 442.527mm and roof displacement is 111.286mm. Spectral displacement at yield and spectral displacement at ultimate is calculated from the above results. Figure 4 shows the pushover curve for the base shear vs displacement.

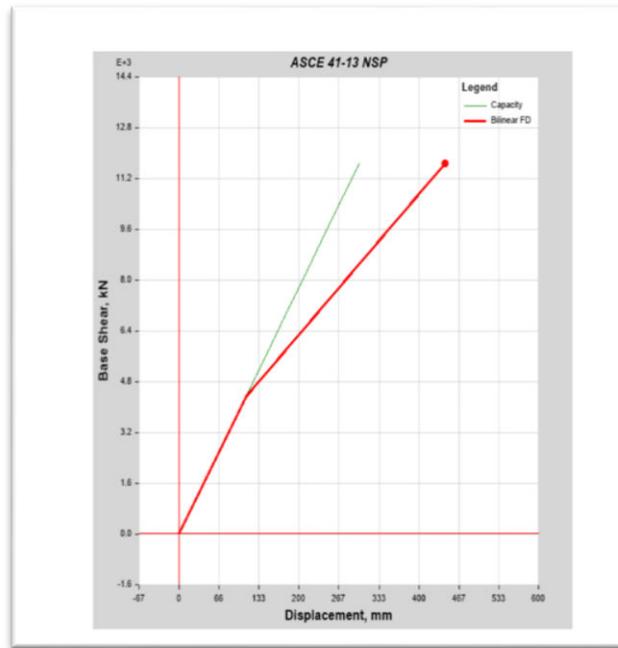


Figure 4 Pushover Curve

The total fragility functions corresponding to the different damage states are computed and the curve is plotted. The maximum probability in the slight damage (SD) state is 85% at maximum spectral displacement. The probability of the structure in complete damage (CD) state is low as compare to slight damage state. Figure 5 shows the fragility curve for probability vs spectral displacement.

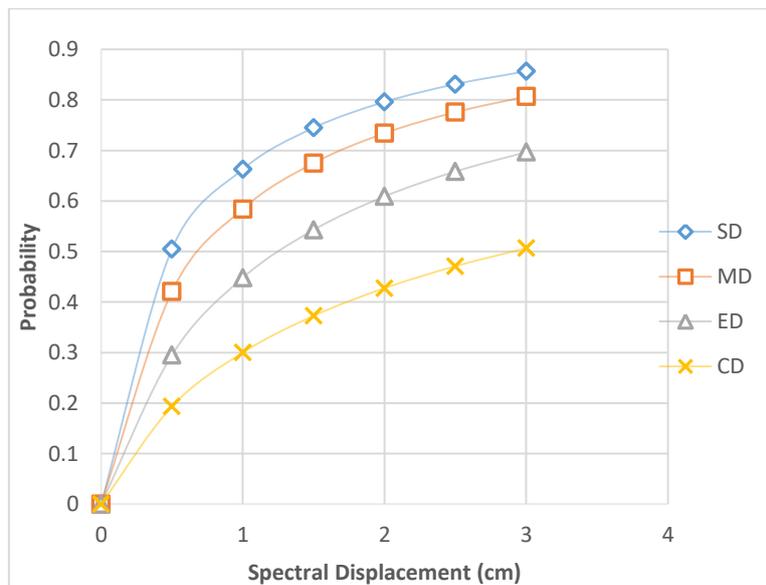


Figure 5 Fragility Curve for all Damage State



In CD state the maximum probability is 50% at maximum spectral displacement. The maximum probabilities moderate damage(MD) and Severe damage (ED) state is in between the 50% and 85%. In the state of MD and ED the 0% and 69% maximum probability for maximum spectral displacement can be achieved. It is observed that the variability of curve between the slight damage state and complete damage state is 50%.

2) Development of Fragility Curve from Time History Analysis (Incremental Dynamic Analysis)

The development of fragility curve from time history analysis by IDA method. The set of 3 Ground Motion recorded in India are considered at increment of 0.1g (g = acceleration due to gravity) for the IDA. The model has been analysed for the Bhuj earthquake having magnitude of 7.0, India-Burma border earthquake having magnitude of 6.4 and Uttarkashi earthquake having magnitude of 7.0. Performance based seismic design is used to derive the fragility points. Performance Based Seismic Design is the design approach that specify the performance of structure at different stages under the ground motion. PBS D can be classified into five categories according to building deformation, namely operational phase (OP), immediate occupancy (IO), damage control (DC), life safety (LS) and collapse prevention (CP). Table 2 shows the percentage of damage measure at five categories. From the results of analysis, the mean and standard deviation is calculated from that the fragility functions obtained for different damage state.

Table 2 Damage Measure (DM)

Damage State	OP	IO	DC	LS	CP
DM %	0.5	1.0	1.5	2.0	2.5

The fragility curve is plotted from the fragility functions corresponding to the different damage states. The probability of OP level is 0% when the PGA is 0 g which is considered as weak ground motions, but the probability of OP level is 100% when exposed to strong ground motion at PGA 0.35 g. Figure 6 shows the fragility curve for all damage for probability vs the peak ground acceleration.

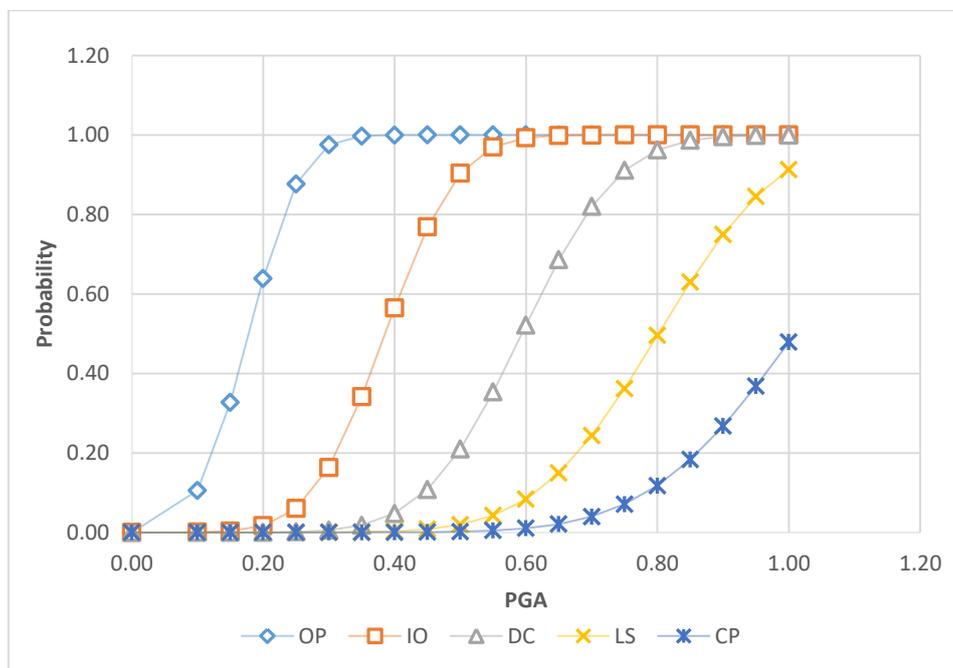


Figure 6 Fragility Curve for all Damage State

The probability of IO state is 100% for the ground motion at and above 0.65 g. The probability is 100% at and above 0.90 PGA in DC state. Probability of structure is 91% for the LS state when the ground motion is 1.0 g. Meanwhile, for CP level, the 48 % probability can be achieved for the ground motion 1.0 g.

d. CONCLUSION

Fragility curve of the structure from seismic analysis is plotted to study the damage probability for different damage state in the building. From the fragility analysis the following conclusions are drawn below,

For Pushover Analysis Based Curve,

1. The maximum probability for slight damage is 80% and for complete damage is 50% at maximum spectral displacement 30mm
2. The structure is safe for spectral displacement at yield and ultimate spectral displacement because in slight damage at 100% probability no damage occurs and for complete damage it requires 100% probability.
3. In the damage state of moderate and severe the maximum probability is 69% and 80% at maximum spectral displacement 30mm.
4. Hence, the structure requires the repairs because at 100% of probability at moderate and severe damage the cracks occur in the structure.

For Time History Analysis (Incremental Dynamic Analysis) Based Curve,

1. For the Operational Phase 100% probability is achieved for the PGA of 0.35g, up to that PGA the structure is safe and no damage occur in the structure.
2. For the Immediate Occupancy damage state at 0.65 g PGA the probability is 100% the minor cracks occur in the structure.
3. In the Damage Control State 100% probability at 0.90g PGA and in Life Safety 91% at 1.0g PGA, the structure requires repairs at both states because at 100% probability of DC and LS state the minor structural damages occur.
4. In the Collapse Prevention state the maximum probability is 48% at ground motion 1.0g PGA, as the PGA increases above 1.0g and at 100% probability of CP state achieved structure starts collapsing.

RECOMMENDATION

1. For increasing the performance of the structure in pushover analysis in the state of moderate and severe damage shear wall can be used.
2. For increasing the performance of the building in incremental dynamic analysis for the state of damage control and life safety retrofitting of the structure can be done.

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